

8th IAASS Conference

Safety First, Safety for All

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Flat H Redundant Frangible Joint

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Flat H Redundant Frangible Joint

Agenda

- Introduction
- Pyrotechnic Component failures
- Flat-H Study
- Lessons Learned
- Flat-H Forward Plan
- White Sands Functional Testing
- New Flat-H Approach
- Conclusion

Introduction

Pyrotechnic devices are commonly used for space vehicle staging and separation events.

These devices are inherently single-use mechanisms that lead to the inability to test and demonstrate failure tolerant performance of actual flight articles.

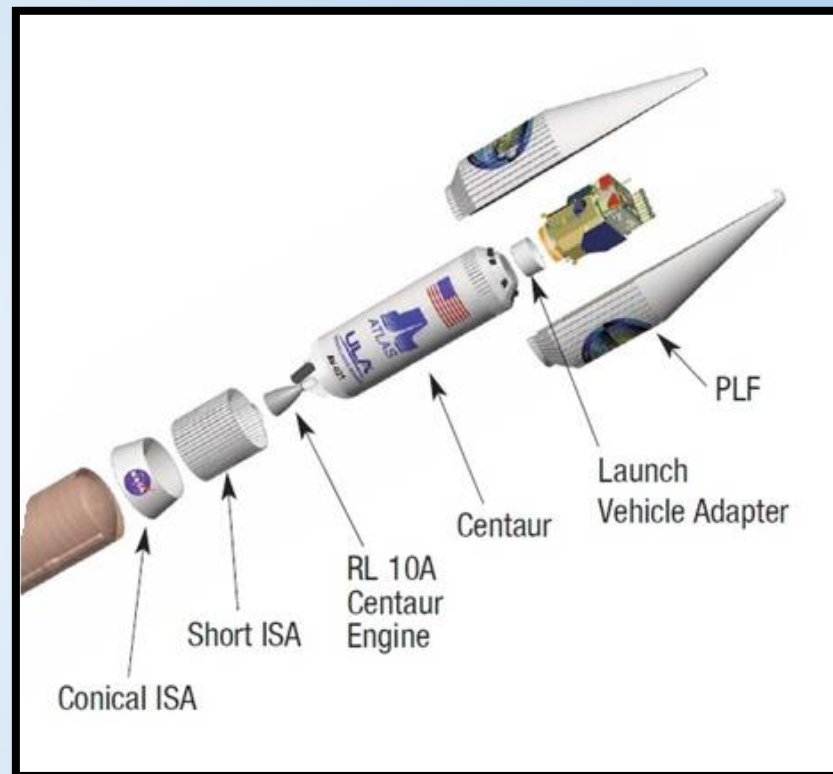
Historically, NASA has implemented a single failure tolerant philosophy for highly critical functions.

The frangible joint is a low weight off-the-shelf system that separates spacecraft structure without generating debris and it induces a lower shock level to the vehicle when fired.

The frangible joints commercially available today are zero failure tolerant and do not provide functional redundancy.

All frangible joints have been used in unmanned spacecraft to date, however, they have been selected for use on the Orion and commercial partners' vehicles.

This presentation discusses the internal development of a single failure tolerant joint design through collaboration of the JSC Engineering and Safety & Mission Assurance organizations.



Applications of Spacecraft Separation Events

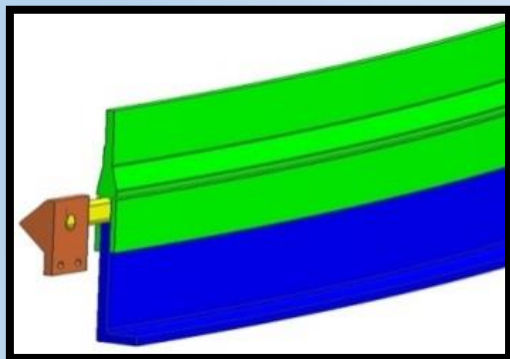
Frangible Joint Operation

Frangible Joint Description

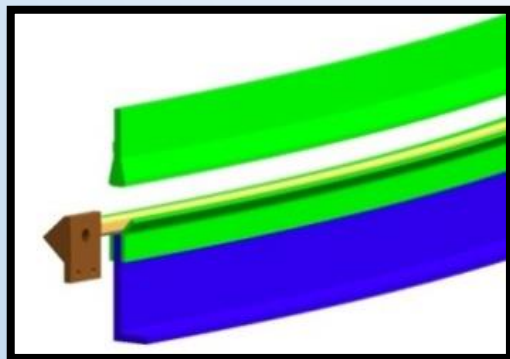
The frangible joint has an expansion tube assembly (XTA), which is installed along the length of the joint separation plane. The XTA consists of a steel tube that has been flattened to create two flat sides, and within the tube are the explosive cord and a charge holder. The charge holder serves to center the cord in the tube and also transmits shock energy to the joint when fired. When the cord is detonated, the tube returns to a round shape and fractures structure along the expansion path. The XTA then contains all debris generated from this event.

These designs are zero failure tolerant.

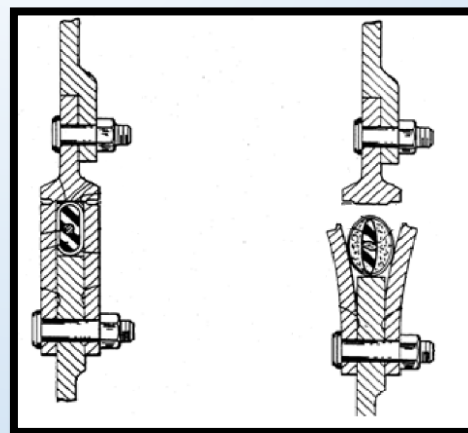
Frangible Joint Functioning



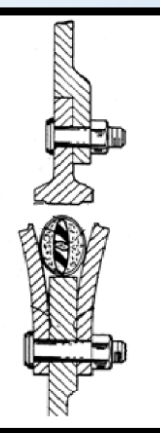
Before



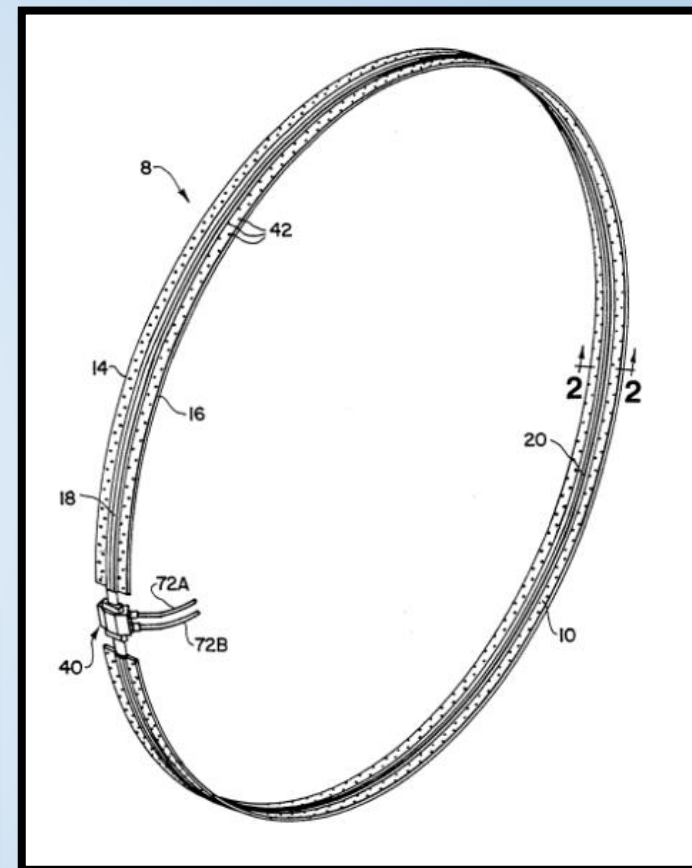
After



Before



After

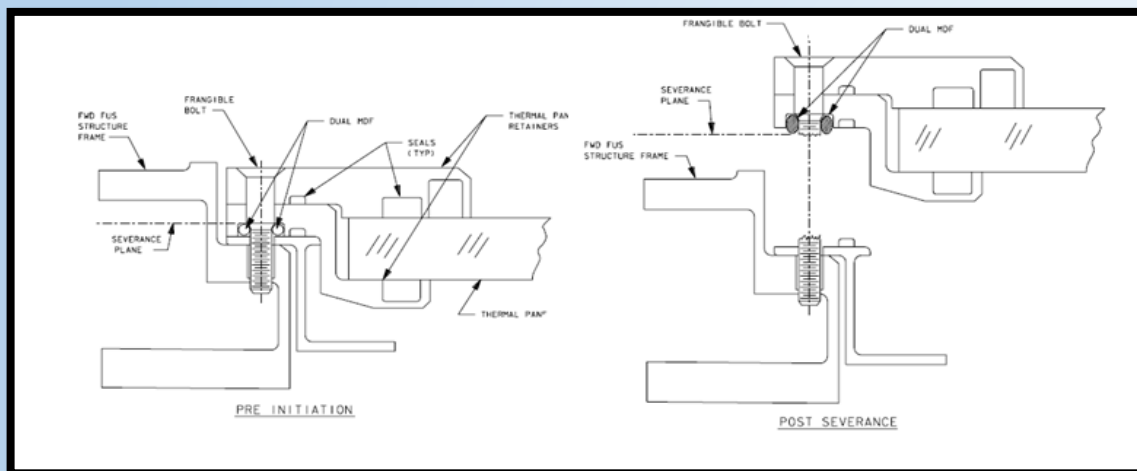


Frangible Joint assembly (FJA)
before vehicle installation.
Larger FJAs consist of several arc
shapes to make a circle.

Pyrotechnic Component Failures

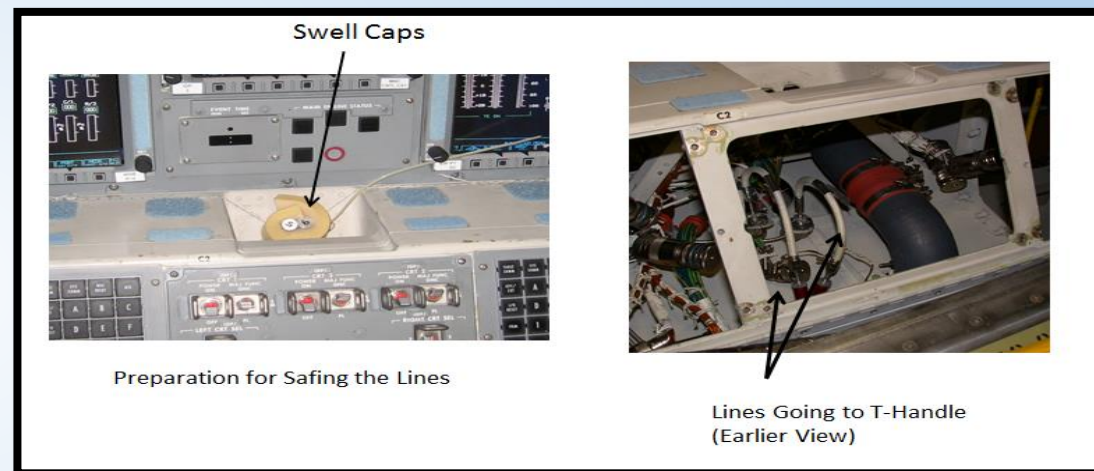
Below are 2 of many cases where linear explosives have failed

Shuttle Overhead Window Jettison Qualification Test



- After a successful jettison of the outer window during a qualification test, inspection revealed that one of the mild detonating fuse (MDF) lines had not fired as planned.
- The root cause of the failure remains unknown. Complete functionality of the system was achieved only through implementation of redundancy.

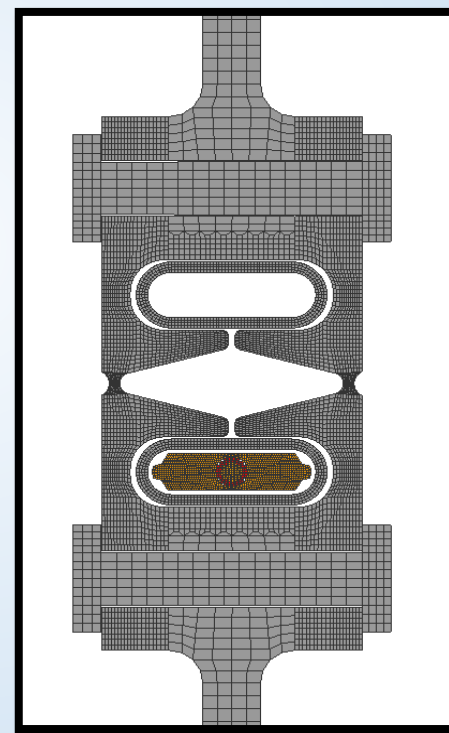
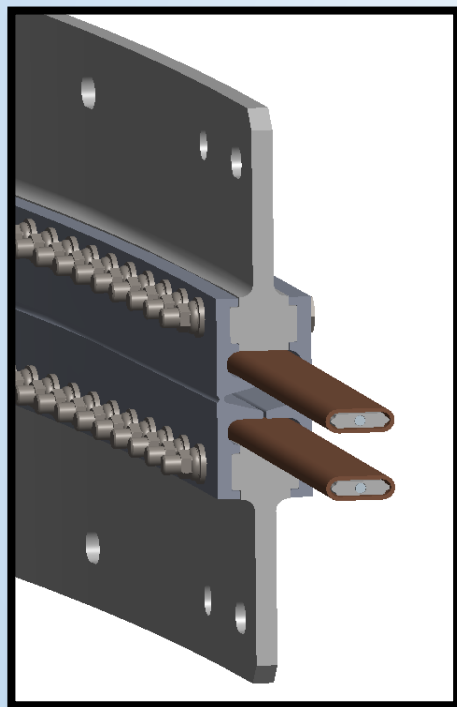
Shuttle Flexible Confined detonating Cord (FCDC) Failure



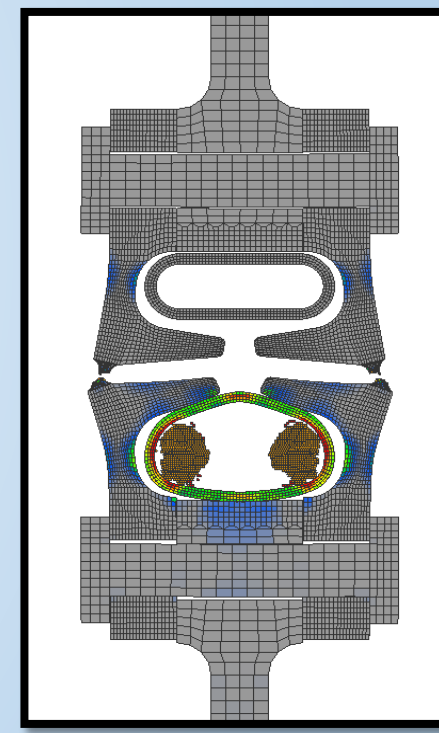
- During safing following Shuttle retirement, these lines were functioned in place due to the extensive efforts required for complete removal.
- One of the caps did not swell as expected indicating that the line did not fully function.
- Functionality would not have been compromised due to the redundant design.

Flat H Redundant Frangible Joint Design

- NASA JSC's Safety and Engineering organizations teamed up to develop a new design that is fully redundant.
- The Flat H design consist of two XTA's that act on one separation plane.
- Models were created to assess adequacy of designs.



Before



After

Flat H Redundant Frangible Joint Assembly and Functioning

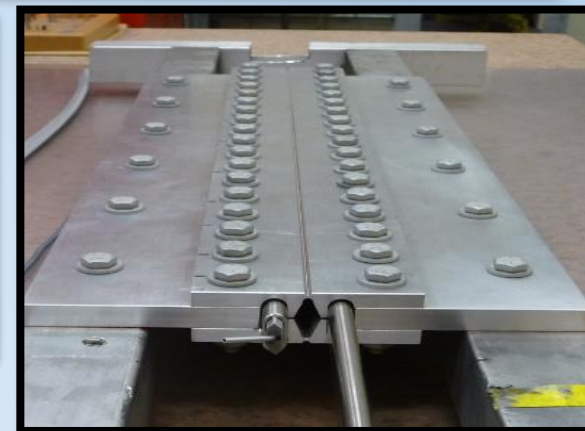
Initial Flat H Frangible Joint Testing



Early Testing
Mixed Results

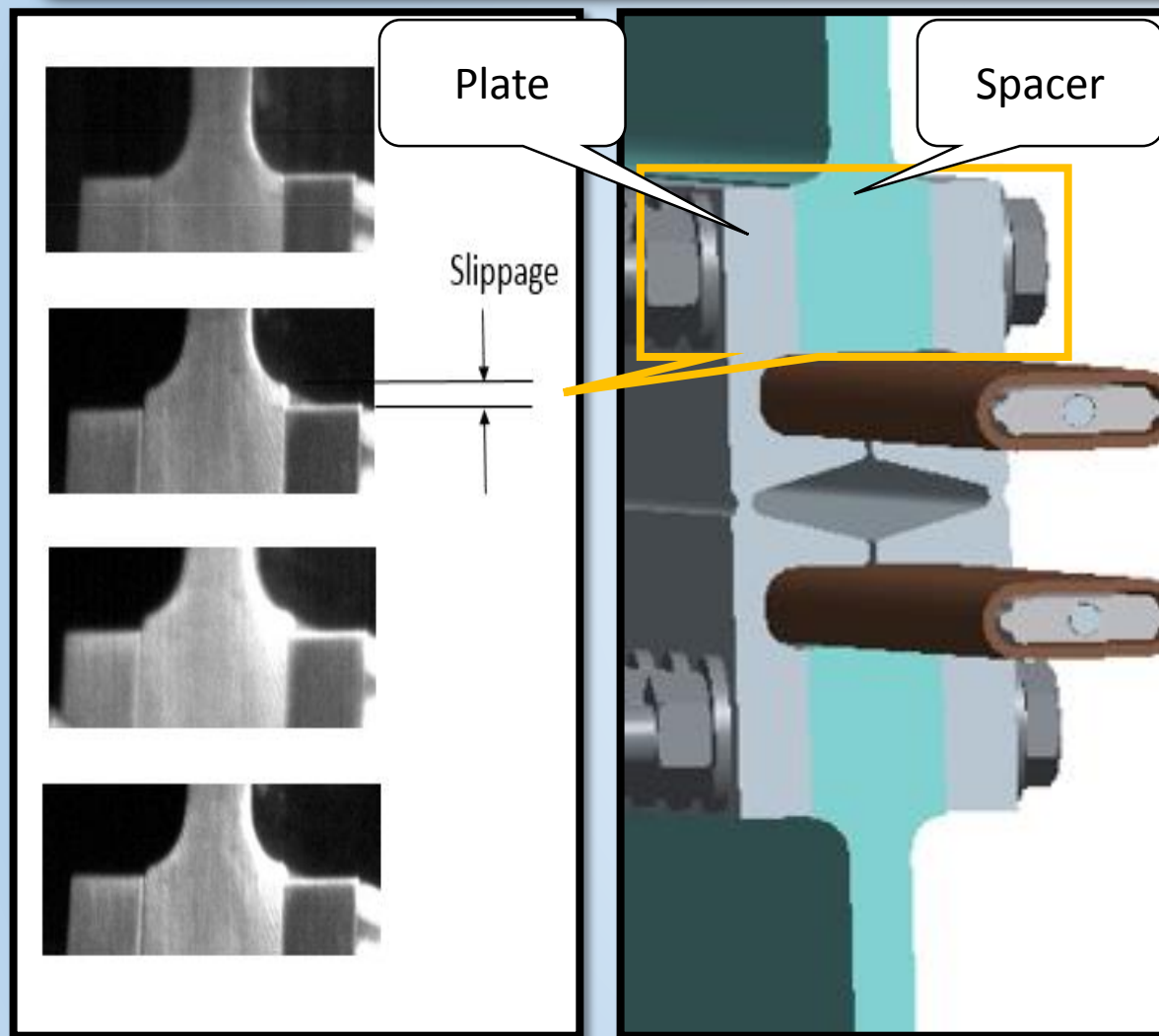
- In early 2014, the Propulsion and Power Division funded the first proof of concept testing for 3 assemblies.
- Testing showed positive results.

- Later in 2014, NASA Headquarters funded additional testing both at JSC and White Sands Test Facility (WSTF). This design was modified to fit Orion's Panel Separation.
- Testing showed mixed results between the JSC and WSTF results.
- Further testing was completed with larger explosive cord sizes, but problems remained with the design when tested at WSTF.



Proof of Concept Testing

Initial Flat-H Lessons Learned



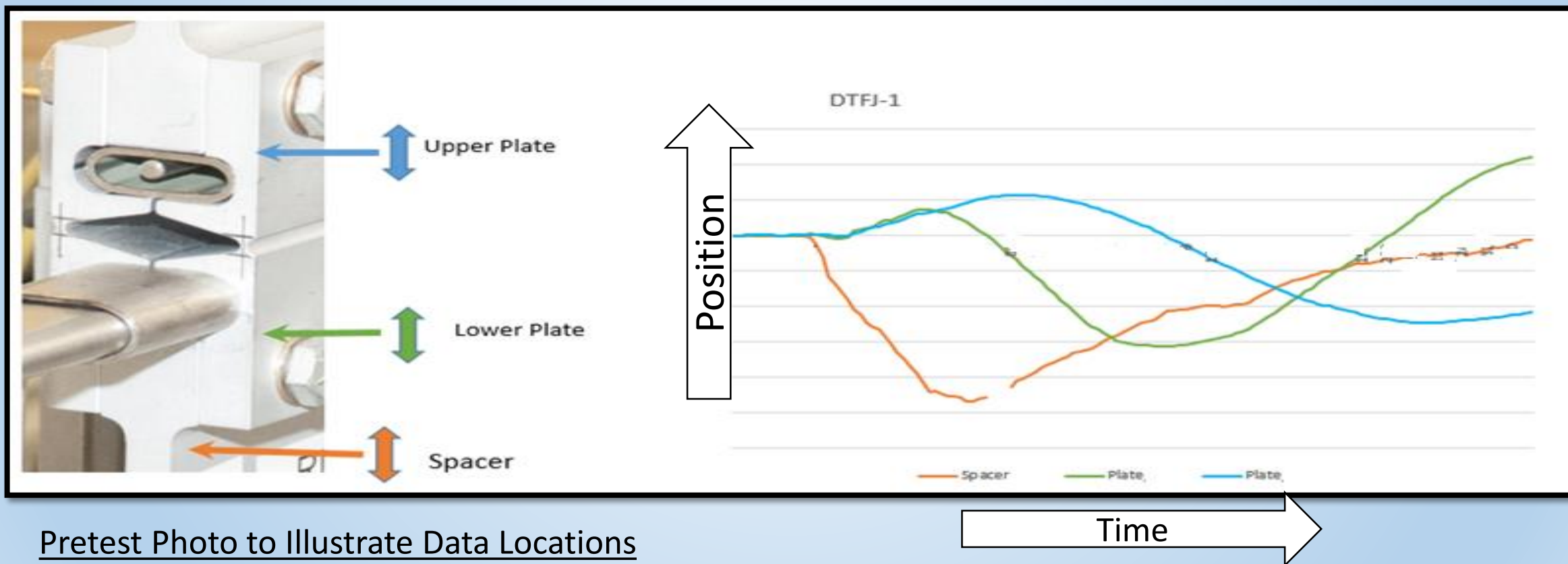
Spacer/Plate Slippage caught on High Speed Video

- Many lessons were learned from these initial test efforts.
- One big design factor that was not considered a risk was the diameters of the holes and the bolts attaching the parts together.
- Hole diameters were bigger in these parts than the original proof of concept test articles.
- The variation was known, but could not be changed prior to the WSTF testing.
- Upon firing, with larger explosive cord loads, the joint failed to separate.
- After analyzing the test data it was noticed that there was movement between the plate and spacers.
- The movement led to energy loss and greatly reduced the energy directed toward plate breakage.

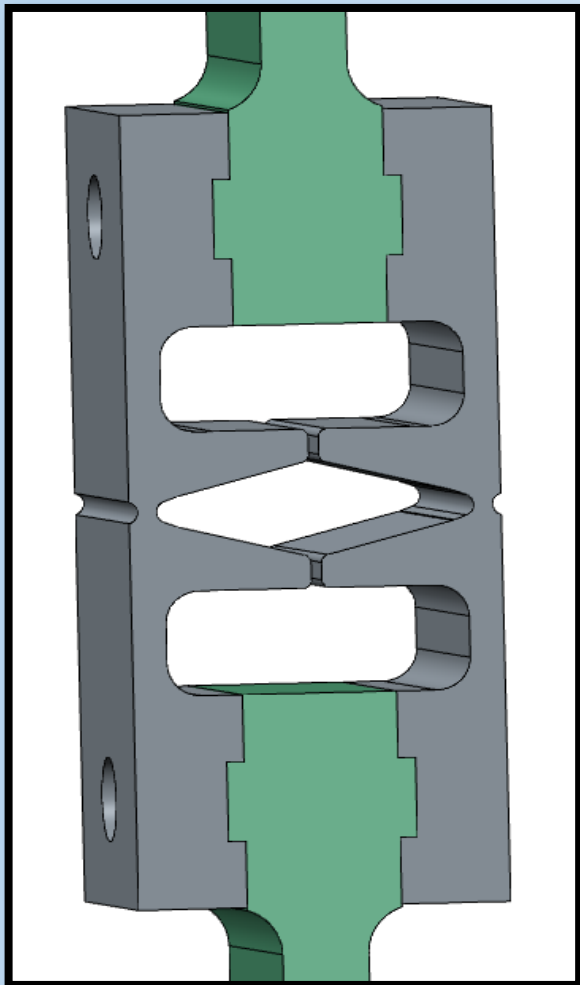
White Sands Testing

Large amounts of data were analyzed to determine what may have contributed to the failure.

Positional data revealed that there was movement between joint components.



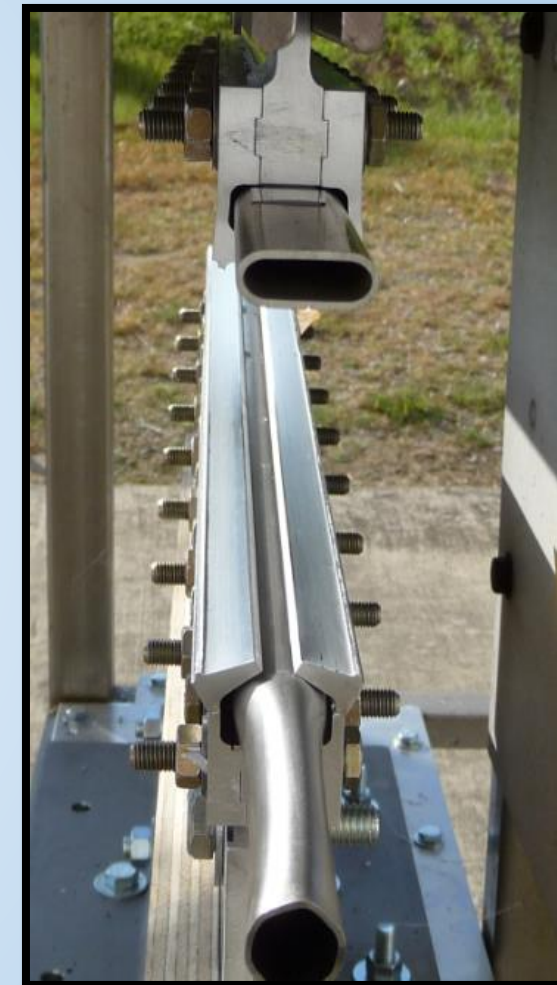
Flat-H Forward Plan



Updates Design for 2015 Tests

To prevent slippage, keyways were cut into the parts.
Geometry changes also made to gain efficiency.

Following tests showed successful separation
with the lower explosive cord size.

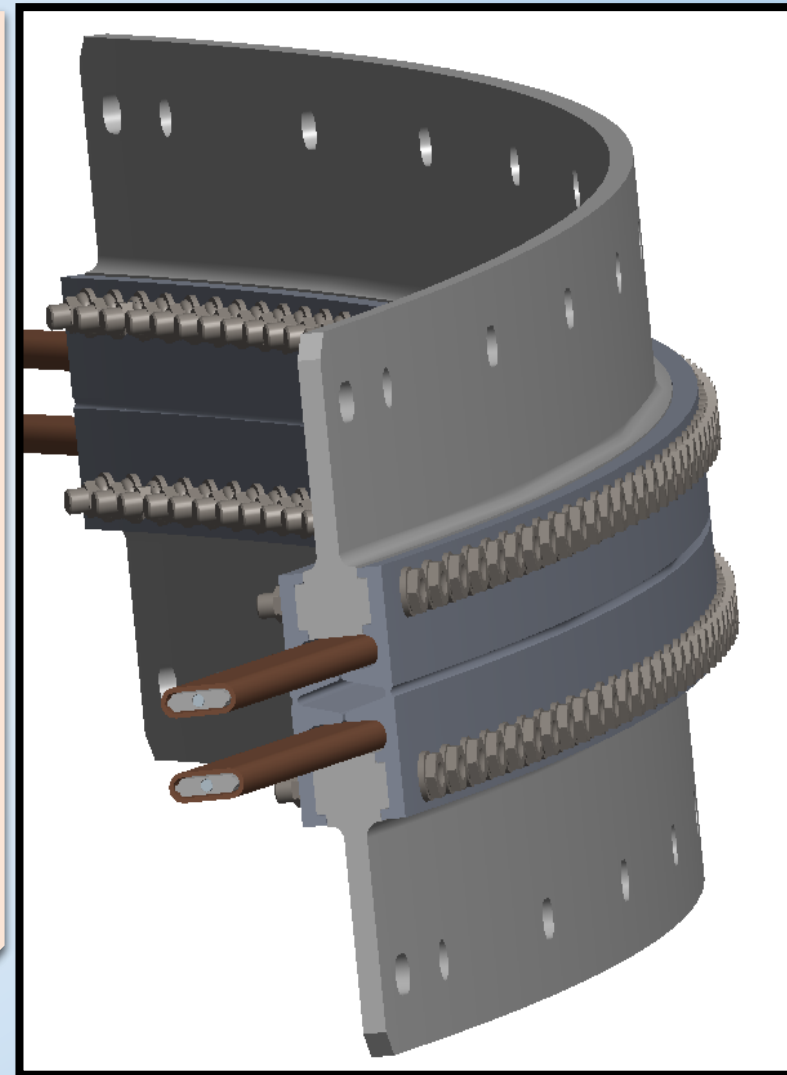


2015 Test Results

Curved Flat-H

Forward Work

- Seek additional funding to continue the development activity.
- Demonstrate feasibility of rolling process.
- Procure notch curved sections for combined load tests.
- Examine functionality with full length test articles.
- Continue to perfect analytical models to achieve better predictive test results.



Flat-H Success Story

2014 Flat- H Initial Funding by NASA HQ provided:

- Energetic Systems Test Area Tests
- Structural Load Test
- Compression
- Tensile
- WSTF 4 Functional Tests

2015 Additional Flat-H Funding from the JSC Innovation Fund, JSC Center Innovation Fund (JTWG), and the JSC EP Division showed a strong advocacy for long-term solution and provided:

- WSTF 2 Functional Tests
- In-house LS Dyna Modeling and Analysis
- Energetic Systems Test Area Functional Tests
- Load Tests

Flat-H Forward Plan

- Demonstrate promising Flat-H Design Solution
- Seek funding to emulate Orion vehicle geometry
- Buy down future risks early in development
- Qualification of a flight design

Conclusion

Core Design Philosophy: A single failure tolerant Flat-H frangible joint technology with increased reliability, available for potential use on all human-rated space vehicles starting with Orion Exploration Mission 3, that assures crew safety, and that controls the risk of untestable frangible device failures resulting from:

- Improper installation,
- Poor handling methods,
- Deficient procedures,
- Inadequate manufacturing methods,
- Substandard materials,
- Faulty workmanship.